

# NASP X-30 PROPULSION TECHNOLOGY STATUS

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Successful development of the NASP demands a propulsion system which operates efficiently across the entire NASP operational flight envelope and at speeds ranging from the takeoff to near-orbital velocity. To meet this challenge, research is being conducted to develop specific air-breathing engine designs which exhibit high effective specific impulse using combined subsonic-supersonic-combustion ramjet/scramjet propulsion concepts. Scramjet engine performance critically depends upon effective, synergistic integration of new propulsion technologies with the basic NASP airframe (see Figure 8-1).

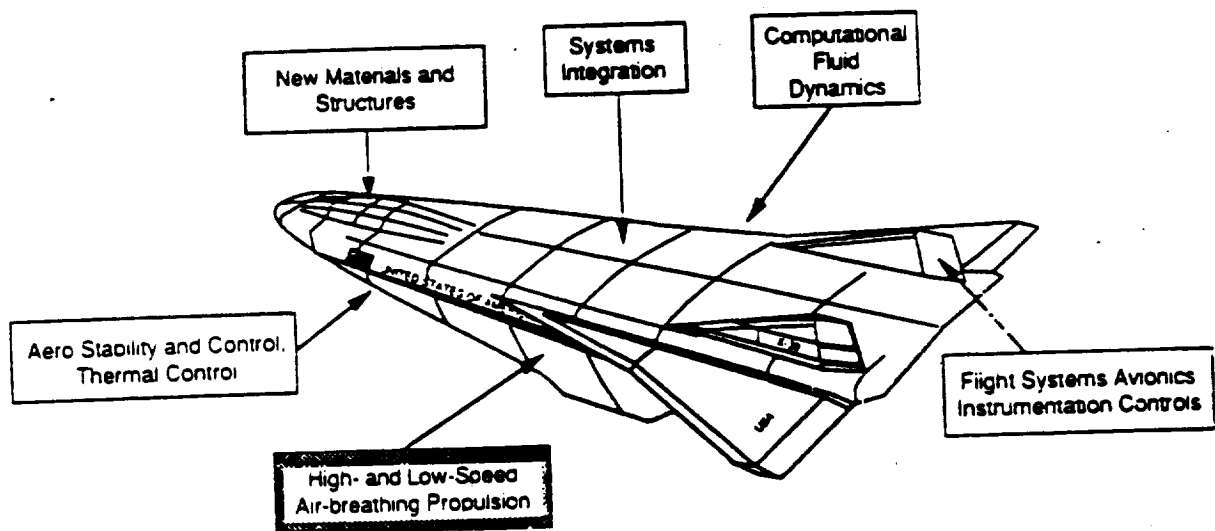


Figure 8-1. The Propulsion Challenge

The performance goals of the NASP program require an aero-propulsion system with a high effective specific impulse. In order to achieve these goals, the high potential performance of air-breathing engines must be achieved over a very wide Mach number operating range. This, in turn, demands high component performance and involves many important technical issues which must be resolved.

Scramjet Propulsion Technology is divided into five major areas: (1) inlets, (2) combustors, (3) nozzles, (4) component integration, and (5) test facilities. Critical areas of focus for the component areas (inlets, combustors, and nozzles) are the resolution of key technical issues, development of a high Mach number design methodology, and establishment of a high Mach number performance data base that will meet the challenging goals of the high performance and minimum weight engine required for NASP. In component integration, integrated models of selected component designs must be tested in order to resolve component integration problems and to evaluate overall engine performance. Test facilities are required (1) to provide Mach 5-8 test capabilities of sufficient scale in order to conduct and support the engine contractors' propulsion module tests and (2) to provide very high Mach number simulations for smaller scale component tests.

The scramjet inlet technology area addresses the key issues of inlet contraction ratio, inlet efficiency and air capture, boundary-layer effects and simulation, shock/boundary-layer interactions, and real-gas effects. The waves in the internal portion of a hypersonic inlet tend to coalesce into a strong shock giving rise to a large adverse pressure gradient. Increasing the contraction ratio aggravates the problem, thereby finally limiting the allowable compression ratio before massive separation occurs. Relatively long forebodies are required to minimize shock losses at high Mach numbers. Consequently, the boundary layer tends to become relatively thick. The airframe shape and type of profile can have a significant impact on inlet performance and its operating characteristics. Also, at very high Mach numbers, the effect of O<sub>2</sub> vibration can become important. Wave structure of any given geometry is unique, and important inlet characteristics, such as air capture, are difficult to match unless properly simulated. Combined analytical and experimental efforts will provide answers to these issues, as well as develop the methodology to design, test, analyze, and evaluate high performance hypersonic inlets. Tests of small aerodynamic models will be conducted over a wide Mach number range, including both wind tunnels and shock tunnels, and will be complemented with applied computational fluid dynamics.

Hypersonic vehicles tend to utilize their long forebodies as part of the inlet compression process. This results in forebody boundary layers being ingested into the propulsion system. In most cases, the complete forebody-inlet system is difficult to model in a propulsion system test. Therefore, a technique to generate thick boundary layers in supersonic flow must be developed with the proper momentum defect distribution.

Studies in the scramjet mixing area address the key issues of penetration, wall and strut injection, supersonic shear layer mixing, and mixing augmentation techniques. Experimental programs are underway to investigate shear layer mixing and hypermixing concepts and to compare these results with CFD codes using modified turbulence models. Several mixing augmentation techniques, including longitudinal vorticity production and shock interactions, will be investigated through university grants using the NASA Langley Mach 6 high Reynolds number tunnel.

Shear flow development and mixing characteristics of noncircular nozzles were investigated and compared to a circular jet over a range of Mach numbers at the Naval Weapons Center (NWC), China Lake, California. Hot wire measurements and schlieren photography were obtained. The superior mixing characteristics of elliptic and rectangular jets relative to the circular jet, which were known to exist for subsonic jets, were also found in the transonic jet and were further augmented by the shock structures of the supersonic under-expanded jet.

Areas to be investigated in hypersonic mixing are effects of incoming boundary-layer turbulence, longitudinal vorticity production, surface distortion, and shock enhancement.

The scramjet combustor technology study area addresses the key issues of film cooling/skin friction, ignition enhancement/flameholding, combustor performance, diagnostics, and effects of initial conditions. At high flight Mach numbers, protection of the combustor wall is of paramount importance due to the extremely high enthalpies of the incoming flow. Likewise, momentum of the fuel is a major factor, and coaxial injection is required for most fuel to maximize thrust. Film cooling offers the possibility of simultaneously protecting the wall from excessive heat flux and reducing wall shear. However, coaxial injection is not conducive to rapid mixing. Measurements are not only more difficult to make, but they must be more extensive than in a subsonic combustor since in supersonic combustion there is no defined sonic point and exit property profiles are generally nonuniform. Therefore, the entire combustor exit flow field must be measured to accurately assess combustor performance and to provide initial conditions for nozzle flow analysis. Combined analytical and experimental efforts, supplemented by university grants, will clarify these key issues and provide sufficient understanding to design a supersonic combustor capable of operating over a wide Mach number range. New instrumentation techniques and laser diagnostics will provide detailed flow-field measurements with which to calibrate computational codes.

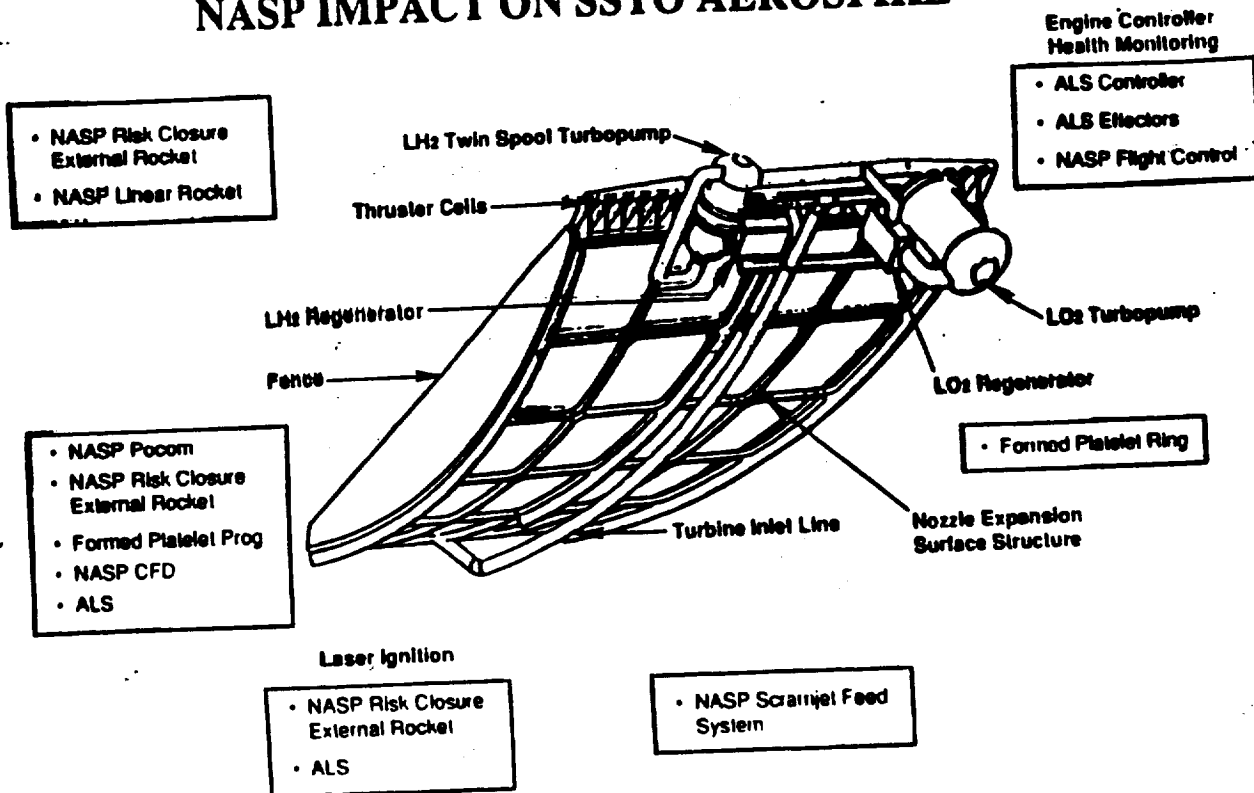
The scramjet kinetics study area addresses the issues of chemical kinetics, reaction rate constants, and enhancement techniques for the three-body recombination reaction. A chemical kinetic data base is being acquired for reliable computer simulation of hydrogen/air supersonic combustion and for tests performed in facilities using vitiated air. A shock tube and high temperature kinetics cell, along with computational chemistry methods, are being utilized to obtain the critical rate constants at required accuracy over a wide range of temperatures. Identification of chemical additives that can speed up the exothermic combining of radical species and experimental evaluation of their effectiveness will be accomplished.

A sensitivity analysis of the hydrogen and air chemical reaction model was performed by Los Alamos National Laboratory to identify which specific reactions are the key rate-limiting steps in the heat release mechanism under conditions relevant to scramjet propulsion.

The scramjet nozzle technology area addresses the key issues of nonequilibrium thermochemical effects, fluid dynamic losses, thrust vector control, and entrance profile effects. A major thrust loss mechanism in supersonic nozzles at high Mach numbers is the thermochemical energy retained by dissociated species when subjected to a rapid expansion process. Other mechanisms which lead to large losses include wall skin friction and heat transfer, divergence, and internal compression waves generated by nonuniform entrance conditions. Combined analytical and experimental efforts will provide answers to these issues and demonstrate internal nozzle performance, as well as develop a data base for flight Mach numbers over a wide range of Mach numbers using both steady state and pulse facilities.

The scramjet component integration technology area addresses the key issues of combustor/inlet interaction, forebody effects on performance, and combustor flow profile/nozzle performance. Flow profiles (including the nature of the boundary layer) coming from one component will affect the performance of subsequent components. For airframe-integrated scramjets, it is especially important to investigate the effects of a simulated forebody flow on the performance of the engine module. Combined analytical and experimental efforts will help answer these issues, as well as develop a broad scramjet data base over a wide Mach number range. Both vitiated and arc-heated freejet NASA Langley scramjet facilities and the Calspan 96-inch shock tunnel will be utilized in establishing early scramjet engine performance levels and resolve any key integration issues.

# NASP IMPACT ON SSTO AEROSPIKE



## Objective:

- Design, Build, Test X-30 Engine Components to Demonstrate Technology
- CFD Codes to Predict Inlet Mass Capture, Combustion Efficiency

## Pay-Offs:

- Revitalized National High-Speed Propulsion Test Facilities
- Extensive Scramjet Data Base
- High Conductivity Materials for Heat Exchangers
- Advanced 3D CFD Propulsion Codes with Accurate Physical Modeling for Mixing, Combustion

## Summary

Execution : NASP JPO, Contractor, GWPs  
Funding : PE 63269F and NASA

Funding (\$M)*	90	91	92	93	94	95	96	97	98	99	00	01	02	Total
Tasks	Prior	91	92	93	94	95	96	97	98	99	00	01	02	Total
X-30 Engine			(1)	(2)	(3)			(4)						
Engine Structure/Material				(5)	(6)									
APTU									(7)					
Flight Test Validation														

- Phase 3 Funding Estimate Provided by Air Staff
- Actual Program Funding Requirement Due 2nd QTR FY92

## Milestones:

1. Concept Selection (4/91)
2. Size Freeze (2/92)
3. Technology Freeze Date (1/94)
4. Engine Delivery (4/97)
5. Material Flight Engine #1 Selection (1/93)
6. Structure Component Tests (3/93)
7. APTU Ram/Scramjet Flowpath Test Facility - FY96

## Propulsion Test Facilities



### Objective:

- Provide Propulsion Technology and Development Test
- Develop Combustor Concepts
- Develop Integrated Engine Configurations

### Pay-Offs:

- Enabling Technology for Wide Range of Revolutionary Mission Concepts
- Free World's Largest Hypersonic Engine Test Capability
- Complete Testing Capability for Airbreathing Engines up to Mach 8
- Full Range of Component Test Capability

Execution : NASP JPO, Contractor, GWPs  
Funding : PE 63269F and NASA

Funding (\$M)*		74.3	18.1	21.4	21.3	37.5	42.2	47.5	51.0	63.3	63.3	63.3	51.0	47.5	80.1
Tasks	FY	Prior	91	92	93	94	95	96	97	98	99	00	01	02	Total
Engine Test Facility (ETF)															
Static Stand															
ASTF															
APTU															
Others															
Flight Test Validation															

- Phase 3 Funding Estimate Provided by Air Staff
- Actual Program Funding Requirement Due 2nd QTR FY92

### Milestones:

1. Subscale High Mach Combustor Development Facilities- 4Q FY92
2. Static Test Stands - FY96
3. ASTF System Test Facility - FY96
4. APTU Ram/Scramjet Flowpath Test Facility - FY96
5. Component Test Facilities - FY94
6. Full Scale Shock Tunnel for Combustor Development
7. LaRC 8' HTT Upgrades FY93

## Ramjet / Scramjet Engines



### Objective:

- Develop and Demonstrate Hypersonic Airbreathing Propulsion Systems
- Innovative Engine Structure Concepts
- Large Scale Scramjet Data Base

### Pay-Offs:

- High Specific Impulse Propulsion Systems
- High Temp. Composites for Heat Exchangers
- Validated Hypersonic Combustion Codes

Execution : NASP JPO, Contractor, GWPs  
Funding : PE 63269F and NASA

Funding (\$M)*		280	70.8	83.5	83.2	145	185	185	185	247	247	247	199	185	2348
Tasks	FY	Prior	91	92	93	94	95	96	97	98	99	00	01	02	Total
X-30 Engine															
Engine Structure/Materials			(1)	(2)		(3)			(4)						
Flight Test Validation					5X6										

- Phase 3 Funding Estimate Provided by Air Staff
- Actual Program Funding Requirement Due 2nd QTR FY92

### Milestones:

1. Concept Selection (4/91)
2. Size Freeze (2/92)
3. Technology Freeze Date (1/94)
4. Engine Delivery (4/97)
5. Material Flight Engine #1 Selection (1/93)
6. Structure Component Test (3/93)

## Advanced Auxillary Propulsion

Execution : NASP JPO, Contractor, GWPs  
Funding : PE 63269F and NASA

Funding (\$M)*		31.9	7.8	9.2	9.2	16.1	16.1	20.4	21.9	27.2	27.2	27.2	21.9	20.4	250
Tasks	FY	Prior	91	92	93	94	95	96	97	98	99	00	01	02	Total
Propulsion System Integration				(1)	(2)(3)	(4)									
Flight Test Validation										(5)					

### Objective:

- Develop Advanced Platelet Rocket Thruster
- Fully Reusable, Throttleable

- Phase 3 Funding Estimate Provided by Air Staff
- Actual Program Funding Requirement Due 2nd QTR FY92

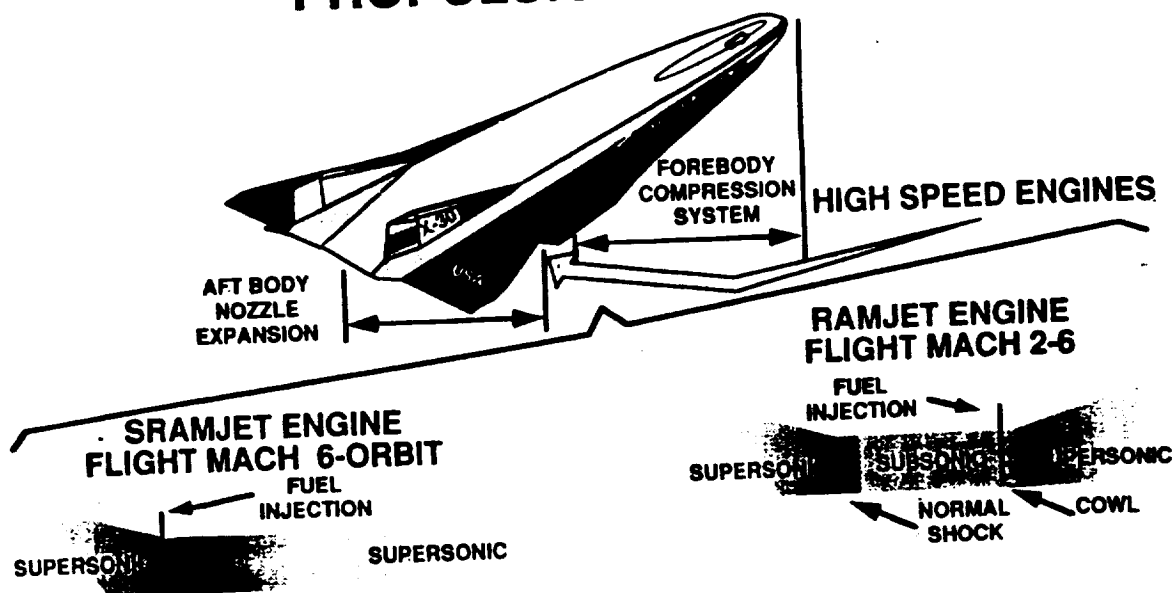
### Milestones:

1. System Design Requirements (9/91)
2. Rocket Configuration Freeze (9/92)
3. System Preliminary Design (4/93)
4. Technology Freeze Date (1/94)
5. X-30 First Flight (10/97)

### Pay-Offs:

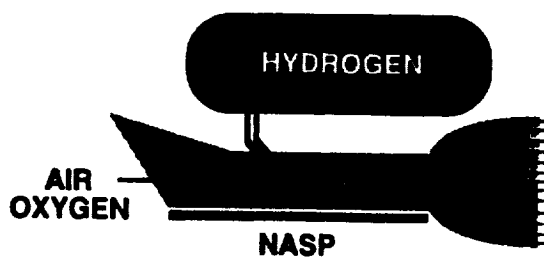
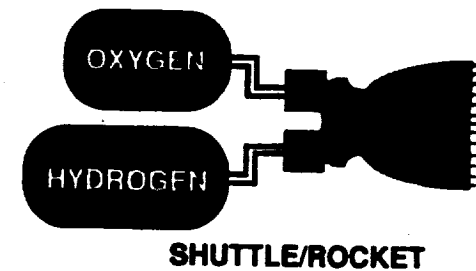
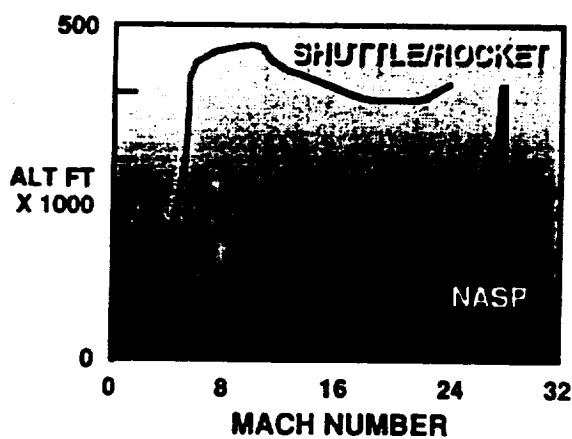
- High Performance 2-D Rocket Demonstrates ASO SEC ISP
- NASP Modular Platelet Engine Selected for SDIO SSTO Concept
- Reliable Electric Restart Via Laser Ignition System

## HIGH SPEED AIRBREATHING PROPULSION SYSTEM



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## PROPULSION MODE COMPARISON



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**NASP X-30 Propulsion Technology Status (Industry)**  
**D. Kenison**  
**NASP JPO**

**(Paper Not Received in Time for Printing)**

